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Potato Spraying and Dusting Experiments 1929 to 1931

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BULLETIN 362

POTATO SPRAYING AND DUSTING EXPERIMENTS 1929 TO 1931

REINER BONDE[1]

INTRODUCTION

The potato spraying and dusting experiments carried on in Maine from 1921 to 1928 inclusive, are summarized in the Maine Agricultural Experiment Station Bulletins 334 (Folsom and Bonde, 1926)[2] and 352 (Bonde *et al.*, 1929).

The experiments from 1929 to 1931 were conducted in an effort to supply the information needed with regard to the control of both late blight and early blight under practical farm conditions. The enormous losses suffered through the ravages of "Potato rust"[3] had demonstrated clearly that many farmers did not control that disease in seasons of severe epidemics. The questions were justly asked, "Can late blight or potato rust be successfully controlled on commercial farms in Aroostook County? If this disease can be controlled, what are the reasons why the majority of farmers often experience losses in blight years?"

It has seemed advisable also to continue comparative studies of dust and spray fungicides. These materials involve the use of quite different methods of disease control. Growers very often inquire as to the relative merits of copper-lime dust and Bordeaux mixture, and are continuously demanding information that will help them to decide whether dust or spray should be used on their farms. Our policy is to test the different fungicides under the same field conditions and give unprejudiced information to the farmers.

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[1] Acknowledgment is made of help received from Dr. Donald Folsom on plans, yield determinations, literature, and manuscript, and from Mr. S. O. Hanson and Mr. D. B. Lovejoy on yield determinations.

[2] Reference is made by name of author and year of publication to Literature Cited, which begins on p. 230.

[3] In Aroostook County the term "rust" is commonly applied to late blight due to *Phytophthora infestans* (Montagne) De Bary.

It is advisable to secure more accurate information regarding the benefits derived from spraying and dusting potatoes in Aroostook County. This necessitates the securing of data over a long continuous period. Data have been secured for the past 16 years comparing sprayed and non-sprayed plots. It is felt that data should be available for a twenty-year period in order to warrant the drawing of definite conclusions regarding the benefits secured from spraying. Dust has been included in our tests for a period of eight years.

The Aroostook potato grower is in need of new fungicides or spray practices that will insure larger returns. There is a possibility that new chemicals may prove worth while. Certainly there is need for a thorough study regarding the methods of application and the equipment used in applying fungicides to potatoes in Aroostook County. Within recent years, advances have been made which resulted in more efficient spray rigs that have required additional test plots on our part.

The yield data on Green Mountains for the sixteen-year period from 1916 to 1931, are summarized in Table 1. It may be seen readily from these data that the benefits derived from spraying vary immensely from year to year. In some years the gains have been too small to pay for the extra cost involved; in fact in some seasons yield losses have actually been experienced from the application of fungicides. (See yields for 1923 and 1929.)

Although spraying may not pay in some seasons, there are other seasons when blight is serious and spraying is highly profitable.

It is seen that the average increase to be expected from spraying is 29.5 bushels or 10.9 barrels per acre. This increase amounts to approximately 9 per cent of the crop of unsprayed plots. Whether or not this average increase in yield is large enough to pay for the costs involved would depend on various factors including the cost of applying the fungicidal material and the selling price of potatoes.

The general practice of spraying or dusting is advocated as insurance and protection in seasons of severe disease epidemics. The problem of spraying and dusting potatoes is somewhat different in "Aroostook" than in other potato-growing regions. The summers in northeastern Maine are comparatively cool so that

TABLE 1

Yields[1] from Sprayed, Dusted, and Untreated Green Mountain Plots on or near Aroostook Farm 1916 to 1931 Inclusive[2]

Year	Yield of untreated check plots per acre		Bordeaux mixture plots. Difference from check plots in yield per acre[3]			Copper-lime dust plots. Difference from check plots in yield per acre[3]			Remarks
	Bus.	Bbls.	Bus.	Bbls.	%	Bus.	Bbls.	%	
1916	356	129	+ 9	+ 4	+ 3				
1917	221	80	+62	+23	+28				
1918	379	138	+13	+ 5	+ 3				
1919	305	111	+17	+ 6	+ 6				
1920[4]	(221)	(80)	(+62)	(+23)	(+28)				
1921	411	150	+21	+ 7	+ 5				
1922	216	78	+41	+16	+19	+41	+16	+19	
1923	411	150	—58	—21	—14	—37	—14	— 9	
1924	365	133	+ 5	+ 1	+ 1	—12	— 4	— 3	
1925	320	116	+42	+16	+13	+34	+13	+11	
1926	321	117	+22	+ 8	+ 7				
1927	322	117	+46	+17	+14				
1928	347	126	+50	+18	+14	+66	+24	+20	
1929	403	147	—12	— 4	— 3	—27	—10	— 7	
1930	308	112	+76	+28	+25	+44	+16	+14	
1931	338	123	+76	+28	+22	+45	+16	+13	
Ave. 15 yrs.	334.8	121.8	+27.3	+10.1	+ 9.5[6]				Years 1916-19, 21-31
Ave. 16 yrs.	327.7	119.1	+29.5[5]	+10.9	+10.68[6]				Years 1916-31 as given
Ave. 8 yrs.	338.5	123	+27.5	+10.25	+ 9.6[6]	+19.25	+ 7.1	+ 7.25[6]	Years 1922-25, 28-31

[1] The yields included in the tables and text of this bulletin include only the rot-free tubers at digging-time. Storage rot was practically absent in the recorded experiments. Occasional tests of grading by size showed that it had little or no effect on the comparative yields.

[2] 1916-25 from Maine Agr. Exp. Sta. Bul. 334, p. 244; 1926-28 from Maine Agr. Exp. Sta. Bul. 352, p. 104, 107, 112.

[3] Gain indicated by + and loss by —.

[4] Assuming yields and losses to be the same for 1920 as for 1917. No yield data are available for 1920, but late blight was very severe, as in 1917, so that the inclusion of assumed figures is thought to make this summary more reliable for the estimation of benefits to be derived from spraying.

[5] The average gain of 29.5 bushels is 9.00 per cent of the average yield of 327.7 bushels.

[6] Based only on preceding figures in the column of percentages.

spraying for protection against potato tipburn and other damage due to excessive heat and drying winds is not necessary. It is also unnecessary to spray against direct insect damage because leafhoppers are exceptionally scarce and flea beetles seldom cause noticeable damage. Spraying in Aroostook County is done largely for the control of late blight and early blight either of which may cause considerable losses in yield. Therefore it is not surprising that

information secured from other potato regions is not altogether applicable to Aroostook County.

All the experiments described in the present bulletin were conducted with the Green Mountain variety.

FIELD TECHNIQUE

PLOTS

In commercial practice the booms of wheel-traction sprayers cover four or more rows, while with tractor-power sprayers (Figure 21) usually eight or more rows are covered. Furthermore, ordinarily a large continuous area is sprayed in the same manner. In our experimental work usually only four rows were covered at a time, and each four-row strip received a different treatment from the adjacent four-row strip. This was frequently commented upon by growers visiting the plots, and deserves some mention here.

The potato dusting and spraying experiments as conducted on Aroostook Farm might be considered impractical and not a true criterion by which to determine the practices that should be followed by the commercial growers. It is true that the small-replicated-plot system of comparing the different fungicides is not wholly comparable to the actual and practical field conditions of Aroostook County. It is felt, however, that the small plots serve a need, since the results obtained from such plots are more readily subjected to statistical treatment and supply data which may be more reliable than those obtained from a smaller number of large plots. The larger plots on the other hand may be considered of value for testing the conclusions derived by means of the small plot method. More recently larger plots have been included in the series of experiments for comparison with the small plots. The advantages of the large plots seem to be more hypothetical than real.

Probably the chief disadvantage of the small plots is the effect of disease-spread from untreated check plots to adjoining rows. Whether or not the drifting of the fungicides, especially into the non-sprayed control or check plots, also is a factor that should be considered seriously, is shown by the analysis for metallic copper from non-sprayed check plots that were adjacent to sprayed plots.

Only a trace of metallic copper has been found on the checks. (Folsom and Bonde, 1926, pp. 276-278.) Further, as is shown in Figures 17, 18, and 19, the line of demarcation between sprayed plots and those not sprayed is quite definite. Generally the influence of the drift does not extend beyond the first row. In Figure 20, a single row left unsprayed and bordered on both sides by sprayed rows shows very clearly the effect of missing only one spray application. In this case if spray-drift from the neighboring rows had been very important its effect certainly would have been manifested by checking disease-spread. It has been concluded that, in spite of any drifting, well replicated small plots are more reliable than larger plots with less replication.

The soil available for our experimental spray plots is variable. This has necessitated the use of as many replications as the land available would permit. In our plot work on Aroostook Farm it has been considered advisable to replicate from 10 to 18 times.

The plots are generally 4 or 8 rows wide depending on the kind and length of spray boom used. No attempt was made to cover more than 4 rows with the wheel-traction sprayer. With the tractor-power machine (using three nozzles to the row) either four or eight rows were covered depending on the nature of the experiment. Here the eight-row boom was constructed so that six nozzles could be shut off from each side thus making a four-row strip. The strips receiving the different treatments have been approximately 500 feet long. These strips are cut by cross-alleys into sections ranging from 150 to 240 feet in length, which are considered here as replications. Yields for most of our studies have been based on healthy tubers from the two middle rows only. Thus it is seen that the yields are secured from 300 to 480 feet of row in each plot.[4]

In studies involving harvesting at different dates, or securing data from fields that had not previously been planned for yield data, we have found it desirable at times to use single-row strips 50 or 100 feet in length. Information secured from such data has proved valuable but probably is not as reliable as data secured from plots with more rows and of greater length.

[4] The rows are about three feet apart, which would give approximately 14,520 feet of row in an acre.

Although we have not made a thorough study of plot technique as applied to potato culture in Maine, the attempt has been made to have relatively long and narrow plots. Regarding the advisability of long, narrow plots, Christidis (1931, p. 36, in his conclusion) makes the following statement, "In the light of these investigations, in order to reduce the effect of soil heterogeneity, the plots used should be as long and narrow as possible. This, of course, within the limits set by different practical considerations, amongst which convenience, competition (when acting), and the accurate measurement of the width appear to be the most important."

The plot yields are finally subjected to biometrical interpretations employing the usual method.[5] In many of our yield tests the plots are arranged so that adjacent or nearly adjacent plots may be paired and analyzed by Student's method (Love, 1924; Love and Brunson, 1924). In most of our work the data are compared by the two methods. It is of course well known that statistical calculations cannot take the place of good judgment in planning the experiment, gathering the data, and interpreting the results.

CORRECTING FOR THE EFFECT OF WHEEL INJURY

Our yield rates, as has been stated, usually are based on the weight of rot-free tubers harvested from the two middle rows of the plots. With a four-row wheel-traction type of machine all of the rows receive approximately the same amount of mechanical injury. However, when an eight-row tractor-power machine is employed the two outside rows on each side (4 of the 8) receive no injury while each of the two middle rows is injured on both sides and each of the two rows bordering these two middle rows (one on each side) is injured only on one side. The following chart will illustrate what is meant.

[5] The formula used for the probable error of the mean is $\pm .6745 \frac{S.D.}{\sqrt{n}}$ in which S.D. refers to the Standard Deviation and n to the number of measurements. The probable error of the difference between two means is calculated as the square root of the sums of the squares of the probable errors of the means.

Rows 1 and 2 - not injured
Row 3 - injured on one side
Row 4 - injured on both sides
Row 5 - injured on both sides
Row 6 - injured on one side
Rows 7 and 8 - not injured

In some of our studies on 8-row plots, yields are taken from all the sprayed area or from half of it (rows 1 to 4 or 5 to 8). With such determinations the use of a "wheel-injury factor" is obviously not needed. However, if the yield is determined from rows with either more or less than the average amount of injury, it of course does not represent the commercial yield rate, meaning by this the yield per acre with all rows dug and a standard boom used.

In order to determine the commercial yield rate for plots where the tractor-power machine had been used with only the middle rows dug, it seemed advisable to correct for wheel injury and to calculate the yield for the entire plot on the basis of the yield from the middle rows. In order to correct for wheel injury a "wheel-injury factor" was formulated.[6] The necessary information for the use of this formula was derived from individual row weights in 8-row plots. (See Table 2.) The yield from the middle rows was then multiplied by this factor.

The effect of the wheel injury in spraying and dusting operations has not been thoroughly studied. Recently Dean has called our attention to reduction in yield as a result of injury from the sprayer wheels and cites a case on Long Island (Dean, 1931, p. 99) in which the yield was reduced 68 bushels per acre (7 to 8 per cent) because of this injury. Fitch (1932) also has noted losses from similar causes in Iowa.

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[6] The following formula was used in deriving a factor for the correction of wheel injury.

$$\text{W. I. F.} = \frac{2b + 2o + 4u}{8b} = \frac{b + o + 2u}{4b},$$

where W. I. F. is Wheel Injury Factor,
b is yield from a middle row (injured on both sides)
o is yield from row injured on only one side
u is yield from uninjured row.

TABLE 2

The Effect on Yield of Vine Injury Occurring during Bordeaux Spraying[1]

Machine	Rows	Yield per acre 1930		Per cent reduction due to injury[2]	Yield per acre 1931		Per cent reduction due to injury[2 3]
		Bushels	Barrels		Bushels	Barrels	
Tractor power	Outside 4 rows; no injury	413	150	----------	447	163	----------
Tractor power	Next middle pair; injured only on 1 side	397	144	3.87	453	165	1.34[4]
Tractor power	Middle rows; injured on both sides	353	128	16.99	379	138	15.21
Wheel traction	Any	--------	--------	----------	417	152	6.71

[1] As stated in the text, all the experiments described in this bulletin were conducted with the Green Mountain variety. This applies to Tables 3 to 10.

[2] Based on yield of outside uninjured rows of tractor-power strip. The yield rate per 8 rows, applying the wheel injury factor of $\frac{b + o + 2u}{4b}$, for 1930 would be $\frac{353 + 397 + 826}{1412}$ (= 1576/1412 = 1.116) times the yield rate of the two middle rows. For explanation of the factor see text, p. 183.

[3] The tractor sprayer in 1931 was equipped with vine protectors that appeared to be very efficient in moving the vines from in front of the wheels.

[4] An increase. These rows, injured on one side, yielded more than the adjacent non-injured rows, a fact which is difficult to explain. The middle rows might have been injured to such an extent that the adjoining rows injured on only one side had less competition for space than those rows buffered on both sides by tall heavy foliage.

The question of vine injury has received some attention and study in Maine (Folsom and Bonde, 1926, pp. 265-268; Bonde *et al.*, 1929, pp. 121-122). The yield data for 1924 to 1926 are not significantly in favor of the vine protector. However, in 1927 with the potato vine growth large and with the width between rows reduced to 34 inches, the use of the vine protector increased the yield 19 bushels or 7 barrels per acre which was considered as a significant increase in the light of statistical analysis by Student's method.

The data in Table 2 also demonstrate the amount of loss attributed to vine injury by the wheels of the spray-rig. It is shown by these data that more study should be devoted to ways of reducing this loss. As has been well stated by Dean (1931, p. 100), "We now need careful study of the relative amounts of damage done by different types and sizes of sprayers, tractors, trucks, etc., for the purpose of reducing this damage, while at the same time

keeping or increasing the gains in yield from the action of the spray materials."

It is noted that the loss in yield rate for the injured rows was less for the wheel-traction outfit than for the sprayer drawn by the tractor. However, the loss due to vine injury in the case of the tractor equipment was distributed over twice the area (over 8 rows instead of 4 rows) so that the actual loss per acre was less where the tractor was used. In field practice a 10-row boom is used to advantage by some farmers. Dean (1931, p. 98) maintains that the wheel-traction sprayers are limited to 4 rows because of the lower pressure generated. Many growers, however, are using 6-row booms with wheel-traction outfits. The writer believes that a 6-row boom can be successfully used with good wheel-traction machines.

Both sprayer outfits used in these tests were equipped with vine-protector devices. The vine protectors on the wheel-tractor machines could, no doubt, be improved. Those on the tractor outfit gave excellent protection against actual wheel damage to the foliage. The greatest reduction in yield resulting from the use of the tractor equipment did not seem to the writer to be due to vine destruction. The heavy tractor and the two hundred gallon sprayer greatly packed the soil in the rows over which they passed. The large cleats which dig into the soil also must cause considerable injury to the root systems of the plants in the four middle rows.

The available studies have disclosed the large losses inflicted by wheel injury during the spraying process. Much of this injury may be eliminated by the use of vine-protecting devices. The gain will vary greatly with the existing conditions, depending somewhat on the size of the vines and the distance between the rows. It is best to start the use of the protector at the first application and to drive always in the same furrows and in the same direction, as otherwise the device will cause more damage than it will prevent. Some studies could well be made on the matter of perfecting the vine protectors now in use. There is need also to study different types of wheels, sizes of tractors, trucks, etc., with regard to the amount of damage done by them to the potato foliage.

SEASONAL DIFFERENCES

The spraying and dusting experiments conducted from 1929 to 1931 are of great interest and of value because data were secured for seasons extremely different regarding the severity of late blight. The season of 1929 was outstanding because of the relative absence of the blight diseases. In contrast, the seasons of 1930 and 1931 were favorable to severe epidemics of potato rust. In those years the losses from diseases were unusually severe and the practices of the growers were given a very severe test. The results obtained from our control studies are thought to be rather representative of the conditions as they existed in Aroostook County. The conclusions derived from these studies, therefore, will be applied to the practical field conditions and problems of the growers, especially in years of severe rust.

EXPERIMENTS IN 1929

The tests in 1929 were conducted mainly for the purpose of comparing copper-lime dust[7] and Bordeaux mixture as fungicides. Fungicides as commonly used in northeastern Maine may reduce the efficiency of the potato plant and thus reduce the yields. (See Introduction and Table 1.) This knowledge led us to study also the effect of less concentrated Bordeaux mixtures.

The plots received 7 applications of fungicide using a total of 660 gallons of 5-5-50 Bordeaux spray per acre (containing 16.5 pounds of copper) or 210 pounds of 25-75 dust (containing 18.75 pounds of copper). The dust was applied in the early morning while the foliage was moist, with a wheel-traction duster. The spray was applied with a 4-row wheel-traction machine. Both these machines were drawn by horses, which injured the vines less than a tractor would have done.

The yield results are summarized in Table 3, giving the average yields with their probable errors. The results show that sprayed plots do not always outyield unsprayed plots. Plots re-

[7] In this bulletin it is sometimes convenient or necessary to designate a material by the trade name. This is not to be construed as a recommendation for that particular material over others of the same general nature.

ceiving Bordeaux mixture at half strength and the check plots receiving no treatment gave the largest yields. Dust was inferior to all of the other treatments.

TABLE 3

Yields in 1929 for Different Spray and Dust Treatments

Treatment				Number of plots	Yield per acre	
Material	Gals.[1]	Lbs.[1]	Lbs. copper[1]		Bushels	Barrels
Bordeaux mixture full strength (5-5-50)	660	--------	16.50	14	391.4±5.47[2]	142.3±2.00[2]
Copper-lime dust (25-75)	--------	210	18.75	12	376.5±8.86	136.9±3.23
Bordeaux mixture half strength (2.5-2.5-50)	660	--------	8.25	10	405.5±5.73	147.5±1.76
None. Check plots	--------	--------	0	19	403.3±3.69	146.7±1.51

[1] Rate per acre for the season. In 7 applications made with horse-drawn machine.

[2] Probable error (P.E.) determined by the formula $.6745 \frac{S.D.}{\sqrt{n}}$ in which S.D. refers to the Standard Deviation and n to the number of plots.

When the data were analyzed by the usual method no significant difference was obtained between any two treatments. The only approach to a significant difference between yields was found in the comparisons between dust (which gave the lowest average yield) and Bordeaux mixture at half strength, and between dust and absence of fungicide (in the check plots). The ratios (between the difference and its probable error) for these comparisons are respectively 2.74:1 and 2.79:1.[3] The use of Student's method of analysis indicates clearly a difference in yield favoring the untreated plots over those sprayed with standard Bordeaux mixture. That spraying may decrease the yield, is a fact seldom appreciated by growers.

That the use of half-strength Bordeaux mixture resulted in the largest yields of any of the different fungicidal treatments, is also of interest. In another test third-strength Bordeaux mixture

[3] According to Love (1924a, p. 86), "ordinarily....it is necessary for a difference to be three or four times its probable error to be significant."

did not control early blight in 1929, suggesting that this concentration is not practical. Further work with reduced concentrations was carried on in 1930 and the question will be discussed later in this bulletin.

EXPERIMENTS IN 1930

The season of 1930 was characterized by the abundance and general distribution of late blight or "rust." This is greatly in contrast with the season of 1929 when the usual diseases were relatively scarce or absent.

PRESSURE VARIATION AND "INSTANT BORDEAUX"

In one series of plots in 1930 a horse-drawn traction sprayer was compared with a tractor-drawn sprayer with "power take-off." (Figure 21.) The introduction of the power take-off sprayer and the prevalence of disease in 1930 premitted our experiments to include some spraying practices that had not previously been tested experimentally in Aroostook. "Instant Bordeaux," having been evolved for use with power spraying, also was tested here.

In this series all the spray treatments gave good control of disease. The yields are found in Table 4 and the plots are listed as they occurred in the field, in rotation from north to south, there being 3 rotation-series. The biometrical comparisons of the different treatments showed that the treated plots were in all cases significantly superior to the untreated controls as indicated by the calculated odds. This fact is greatly in contrast with the results of 1929 when late blight was practically absent and full-strength Bordeaux mixture seemed to decrease the tuber yields.

It has been stated by some that high pressures are very desirable, and even essential, for good disease and insect control. The effects of high pressure on blight control and on yield were tested here in a preliminary manner. High pressure (400 to 500 pounds) did not prove superior in any way to lower pressure (230 to 300 pounds) when the material was applied with the same equipment. Late blight was controlled equally well at both pressures. The yields were 406 and 408 bushels per acre (147.6 and 148.3

barrels) for the high and the low pressures respectively. The small difference of 2 bushels per acre in favor of the lower pressure was not large enough to be significant.

TABLE 4

Yields in 1930 for Different Spray Treatments Including Differences in Pressure and "Instant Bordeaux"

Treatment[1]					Yield per acre	
Material	Machine	Pressure[2]	Gals.[3]	Lbs. copper[3]	Bushels[4]	Barrels[5]
Bordeaux mixture, 5-5-50	Wheel-traction	160-220	585	14.89	384±7.47[6]	140
None. Check plots					308±4.69	112
Bordeaux mixture, 5-5-50	Power take-off	400-500	1100	28.00	406±5.13	148
Bordeaux mixture, 5-5-50	Power take-off	230-300	1041	26.50	408±7.17	148
None. Check plots					317±12.0	115
"Instant Bordeaux", 5-5-50	Power take-off	400	1098	27.95	417±6.23	152

[1] Listed as the plots occurred in the field in rotation from north to south, there being 3 rotation-series.
[2] In lbs. as registered on the gauge of the machine.
[3] Rate per acre for the season. In 8 applications.
[4] Each of the yields given is the average for 7 plots.
[5] Determined by dividing the average number of bushels by 2.75.
[6] For P.E. formula see Table 3.

More recently Tilford (1931) in Ohio considered that a pressure of 400 pounds was more effective than either 200 or 600 pounds in the season of 1929. He recommended 300 to 400 pounds pressure (Tilford, 1931, p. 150). However, in 1930, "when there was very little rainfall to remove the spray, Bordeaux applied at 200, 400, and 600 pounds pressure gave practically the same results." (Tilford, 1931a.) Dean (1929, p. 176), a practical and successful potato grower in New York, states that he has secured good results for 23 seasons with pressures ranging from 200 to 300 pounds. He recommends that the pressure should not fall below 200 pounds. For the past four years (1926-1929) he employed 300 pounds at all times. He also states that perfect control can be maintained by using two nozzles per row slanting in from

each side. Martin (1930, p. 158) found that a pressure in excess of 250 pounds is unnecessary for spraying potatoes in New Jersey. He states that 200 to 250 pounds pressure will give satisfactory results if the boom and the nozzles are properly adjusted.

On Aroostook Farm in large fields, late blight has been successfully controlled, even in years of severity, with a wheel-traction machine having two nozzles per row and applying 100 gallons or less per acre per application with a pressure of 200 to 250 pounds. In 1930, however, the wheel-traction plots that were bordered by the unsprayed check plots suffered somewhat from late-blight infection late in the season. From Figure 17, it can be seen that the wheel-traction spray plots were very green on August 28. A trace of blight was present, however. On September 2, as is shown in Figure 18, the disease had progressed considerably in this series of plots. The plots sprayed with the tractor-power machine were not affected by this late spread of blight from the diseased checks. Thus, it is seen that the tractor-power spray machine was the more effective one against the spread of late blight from adjacent non-sprayed plots during periods favorable to the most rapid spread of the disease. That unsprayed portions of potato fields may be a menace, as a source of inoculum to the neighboring fields, is a fact that has appeared previously in our experiments and that farmers should recognize.

It is evident (Table 4) that in 1930 the wheel-traction plots yielded 22 and 24 bushels less per acre than plots where the power sprayer carried the high and the low pressures respectively. These differences, however, are not statistically superior. Further, the lower yields obtained with the traction sprayer in 1930 and also in 1931 should not be entirely attributed to lack of disease control. It is the writer's opinion that this reduction in yield was due largely to the relatively greater amount of wheel injury administered by the horse-drawn outfit.

The "instant Bordeaux" made up as recommended by Sanders (1918) and by Schneiderhan (1929 and 1929a) was employed. The plots sprayed by this method remained green somewhat longer than did the other plots. The yields were also in favor of "instant Bordeaux" which produced eleven and nine bushels respectively more per acre than did the high and the low pressure plots. These yield differences are not of great significance for these data.

In this series of experiments the wheel-traction plots yielded the least (384 bushels or 139.6 barrels) and those sprayed with "instant Bordeaux" yielded the most (417 bushels or 151.6 barrels). The difference in yield of 33 bushels in favor of "instant Bordeaux" is apparently significant, the odds being 44.87 to 1.[9] As is stated above, the superiority in yield rate obtained where applications were made with the tractor-power machine was due, apparently, not to better blight control but to factors involving difference in foliage injury.

It was also observed that the 585 gallons of Bordeaux mixture applied with the wheel-traction machine gave nearly as good protection against late blight as did the 1041 to 1100 gallons applied with a tractor-power outfit. In view of these results it would seem that the more expensive tractor-power machine is more wasteful of material than the wheel-traction outfit.

DIFFERENT STRENGTHS OF BORDEAUX MIXTURE

The results of 1928 (Bonde *et al.*, 1929, p. 112) indicated that a half-strength colloidal copper was equal if not superior to a standard (5-5-50) Bordeaux mixture in disease control and yield. In 1929, as shown previously, a half-strength Bordeaux mixture gave yield results that were equal to those secured from the full-strength mixture. The results of 1929 were obtained in a season when late-blight infection was very light, and therefore they cannot be considered as giving complete information regarding the merits of decreasing the strength of Bordeaux.

In 1930, experimental spray plots were conducted testing the relative effectiveness of different strengths (half, two-thirds, and full) of Bordeaux (5-5-50) under severe late-blight conditions. In these tests the power take-off spray machine was used, with the pressure maintained at about 400 pounds. The dates on which the plots were sprayed and the approximate amounts applied per acre were the same except that the first application (that of July 11) was omitted for the weakened-Bordeaux plots which were not sprayed until July 18 and 19. Late blight at that time had been

[9] According to Love (1924a, p. 86) "ordinarily, odds of 30:1 are taken to be satisfactory for all practical purposes."

found on several places on Aroostook Farm. This was important because it permitted the plots also to be considered as a test of "delayed spraying."

By August 16-17 a very few infected leaflets were seen in the half-strength plots. At that time it seemed as though this weakened strength would not prevent an epidemic. However, relatively little further spread occurred. It was impossible later in the season to detect that the reduced strengths were inferior, in disease control, to the recommended full strength. The excellent control secured with half-strength Bordeaux mixture in 1930 can be noted in Figure 19. The only apparent difference was that the higher strengths discolored the foliage more.

TABLE 5

Yields in 1930 for Different Strengths of Bordeaux Mixture

Treatment			Yield per acre		Difference in yield rate compared with full strength	
Strength	Gals.[1]	Lbs. copper[1]	Bushels[2]	Barrels[3]	Bushels[4]	Barrels[3 4]
Full (5-5-50)	1079	27.47	377±10.70[5]	137	----------	----------
Two thirds (3⅓-3⅓-50)	954	16.18	391± 9.79	142	+ 14±14.51[5]	+ 5
Half (2.5-2.5-50)	954	12.14	366± 7.14	133	— 11±12.9	— 4
None. Check plots	--------	----------	242± 6.72	88	—135±14.71	—49

[1] Rate per acre for the season. In 8 applications for full-strength and in 7 for the others, made with tractor-drawn power take-off machine.
[2] Each of the yields given is the average for 11 plots.
[3] Determined by dividing the average number of bushels by 2.75.
[4] Gain indicated by + and loss by —.
[5] For P.E. formula see Table 3.

The yields for the different concentrations of Bordeaux mixture are given in Table 5. It is to be observed that there were no significant differences in the yields obtained for the different strengths. The difference of 11 bushels per acre in favor of the full strength over the one-half strength can hardly be seriously considered here. (The odds when full strength and one-half strength are compared are 1 to 1.) It is also of interest that the two-thirds strength yielded 14 bushels more per acre than the adjacent full strength plots. (Here again the odds are only 1 to 1.)

It is evident that no serious results occurred from reducing the strength to one-half of that normally used.

Omission of an Application in August

It was stated that in the reduced-strength plots, the first application was omitted without apparent serious results. In another field, on the other hand, on August 14 one row was imperfectly covered because of nozzle trouble. This occurred during a period when late blight was prevalent and while the foliage was growing rapidly. Because of the omission of this one application of spray. the row became practically defoliated (Figure 20). What might have resulted if an entire field had been similarly treated, may readily be seen.

Comparison of Bordeaux Mixture and Copper-Lime Dust

In 1930, Bordeaux mixture applied with a tractor-power sprayer was compared with copper-lime dust on half-acre areas. These were divided into smaller plots for yield determinations. The dust was applied in two ways commonly used in commercial practice. That is, on one plot the dusting was done in the morning while the plants were moist with dew, and on the other while the leaves were dry.

Approximately 250 pounds of dust (containing 25 pounds of copper) and 1000 gallons of standard Bordeaux mixture (also containing 25 pounds of copper) were used per acre for the season. During the season 8 applications were made, except for the plot dusted while dry, which received 7 applications.

disease control

As in previous years, the spray gave practically perfect control against the leaf diseases. The plot dusted when wet had traces of late blight throughout and matured a week earlier than the spray plots. The plot dusted while dry held up well until August 19, after which it died very rapidly from disease and old age. Generally our results show that the most critical period for blight de-

velopment is apt to occur the latter part of August. The approximate condition of the plots on August 19 was as follows:

Spray.....	10	per cent of foliage dead
Dusted wet.....	15	" " " " "
Dusted dry.....	40 to 50	" " " " "

YIELD COMPARISONS

The difference in the foliage as noted above indicated that the sprayed plots would yield more than those dusted. The comparative yields are given in Table 6. It is evident that the sprayed plots yielded more than those with the dust applied to either dry or wet foliage respectively. The plots dusted while dry yielded 23 bushels less per acre than did the adjacent sprayed plots. The plots dusted while wet, though yielding slightly more than the other dusted series, yielded 44 bushels less per acre than did the adjacent sprayed ones, and so showed a greater decrease than the "dry-

TABLE 6

Comparative Yield Rates for Sprayed and Dusted Plots in 1930

Treatment				Yield per acre		Difference in yield between dusted and adjacent sprayed plots	
Material	Gals.[1]	Lbs.[1]	Lbs. copper[1]	Bushels	Barrels[2]	Bushels	Barrels[2]
Copper-lime dust (25-75) applied to dry foliage	--------	250	25	351[3]	128	----------	----------
Bordeaux mixture (5-5-50). Plots adjacent to preceding	1000	--------	25	374[3]	136	+23	+ 8
Copper-lime dust (25-75) applied to moist foliage	--------	250	25	353[4]	128	----------	----------
Bordeaux mixture (5-5-50). Plots adjacent to preceding	1000	--------	25	397[4]	144	+44	+16

[1] Approximate rate per acre for the season. In 8 applications made with horse-drawn duster or tractor-drawn power take-off sprayer.
[2] Determined by dividing the average number of bushels by 2.75.
[3] The average for 5 plots.
[4] The average for 8 plots.

dusted" plots. The two series of plots were not close to each other, so that it was not possible to make direct comparisons between the two series of dusted plots.

It should be pointed out here that the amount of injury caused by the dusting machine was considerable and must have played some part in reducing the yields. The injury to the plants was much more apparent where the machine was used in moist foliage than where it was used in dry foliage. In the plot dusted while moist, practically all the plants were injured to some extent. The dry-dusted plots were injured much less and this might be the reason why their general appearance was superior up to about August 19. This difference in the amount of foliage injury might also explain the lower yield rate (relative to spray) secured in the plots dusted while moist.

These results justify a common opinion among farmers that it is not advisable to apply spray or dust to potato fields while they are moist with dew. It might be advisable to recommend dusting in the evening and night in preference to dusting in the early morning.

EXPERIMENTS IN 1931 WITH DIFFERENT COPPER FUNGICIDES

The results of previous tests show that the benefits derived from spray and dust applications in Maine are not always as great as expected. In some years the gains have not been large enough to pay for the extra cost involved. Fungicides as commonly applied reduce the efficiency and yield of the plant in years of little blight. Such reduction in yield, aside from that caused by mechanical injury, may be due to the actual toxic effect of the spray material or to the residue left on the leaves which reduces the amount of sunlight actually penetrating the foliage.

The Aroostook potato grower could benefit from new fungicides or from spraying and dusting practices that will insure larger returns. There is a possibility that new chemicals may prove worth while. We have evidence that a reduced strength of Bordeaux mixture not only costs less but also at times gives as high yields as full-strength Bordeaux. A certain expenditure of time and funds has been devoted to the comparison of the different

fungicidal materials employed or recommended for the control of the potato blights. Some of these materials were new when tested.

The copper fungicides tested in 1931 in the main series of plots, are listed in Table 7 together with their relative effectiveness against late blight. The disease spread rapidly in the dusted plots

TABLE 7

Relative Amount of Disease Control by Different Treatments in 1931[1]

Treatment[1]			Extent of disease infection	
Material	Machine	Pressure[2]	August 25	September 10
Bordeaux mixture, 5-5-50	Wheel-traction	180-250	Very light trace. Not enough to count.	Somewhat inferior to adjoining power sprayed plots. Not significantly inferior. 40% dead.
Ditto	Power take-off	400	Ditto	Still quite green, probably 25% to 35% dead.
"Instant Bordeaux", 5-5-50	Ditto	Ditto	Ditto	As Bordeaux plots. May be slightly greener in places.
"Sal-soda Bordeaux",[3] 5-7.5-50	Ditto	Ditto	Ditto	Probably best appearing plot. 35% dead.
"Oxo Bordeaux",[4] 4-50	Ditto	Ditto	All plants spotted with late blight.	No green leaves, stalks mostly green.
Copper-lime dust, 25-75	Wheel-traction	----------	All plants spotted with late blight, 20% dead. Spread rapid since Aug. 20.	95% dead, some green stalks.
None. Check plots	----------	----------	All plants badly infected, 75% dead.	Plants completely dead.

[1] See Table 8 for yields and for other particulars as to treatment.
[2] In lbs. as registered on the gauge of the machine.
[3] Also called Burgundy mixture.
[4] Supplied by Mr. G. E. Sanders of the Ansbacher-Siegle Corporation, New York, and claimed by him to contain 12 per cent copper.

during the latter part of August and by August 25 all the plants that had received this treatment were more or less affected. In this series of plots, about 31 pounds of 9 per cent dust per acre were used at each application, and the total amount of dust used for the season was about 283 pounds per acre. This amount is considerably more than is usually recommended and its failure to give satisfactory control can hardly be attributed to the use of in-

sufficient amounts of material. In these experiments it was shown that dust may be an inferior fungicide during periods of severe disease epidemics.

The yields were lowest for the untreated controls, next lowest for the dusted plots, followed by the Bordeaux traction plots, with the remaining treatments highest in yield. (See Table 8.) The

TABLE 8

Yield Comparisons of Different Treatments in 1931[1]

Treatment[1]				Yield per acre		Increase in yield rate over adjoining checks	
Material and machine	Gals.[2]	Lbs.[2]	Lbs. copper[2]	Bushels[3]	Barrels[4]	Bushels	Barrels[4]
Bordeaux (traction)	732	-------	19	414±2.13[5]	151	84	31
Bordeaux (power)	1,283	-------	33	438±4.49	159	108	39
"Instant Bordeaux"	1,283	-------	33	445±4.33	162	109	40
"Sal-soda Bordeaux"	1,283	-------	33	440±3.94	160	104	38
"Oxo Bordeaux"	1,283	-------	13	439±2.96	160	93	34
Copper-lime dust	-------	283	25.3	383±1.83	139	37	13

[1] See Table 7 for disease records and for other particulars as to treatment.
[2] Rate per acre for the season. In 9 applications.
[3] Each of the yields given is the average for 11 plots.
[4] Determined by dividing the average number of bushels by 2.75.
[5] For P.E. formula see Table 3.

differences between these four yield-levels were highly significant. The inferiority in yield with dust can be largely attributed to its failure to control late blight successfully during the serious epidemic that prevailed in 1931. It can be seen that there was no significant difference in yield between any of the several treatments wherein the power machine was used. Plots sprayed with standard Bordeaux mixture (5-5-50), instant Bordeaux (5-5-50), Burgundy mixture or "sal-soda Bordeaux" (5-7.5-50), and Oxo Bordeaux (4-50) all produced excellent yields with no significant differences. From these data it appears that with the same good sprayer equipment the material was of little significance so far as yield is concerned.

The good yields secured with the use of Oxo Bordeaux are of interest. In Table 8 it is seen that this preparation contained only 40 per cent as much copper as the standard Bordeaux (power) mixture, did not control late blight quite as well, and yet gave excellent yield results. This supports the evidence of 1929 and 1930 that it may be advisable to use reduced strengths of materials.

In the 1931 tests the plots sprayed with the wheel-traction rig having relatively low pressure and applying only 57 per cent as much material, yielded less than did the tractor-power sprayer treatments. This apparent difference in favor of the more expensive equipment cannot, however, be attributed to better disease control. The wheel-traction outfit in these experiments, and in practically all of the other experiments conducted on Aroostook Farm, has given excellent control of late blight. It appears to the writer that the differences shown by these data can be attributed to the difference in the amount of wheel injury. With a 4-row wheel-traction outfit all of the rows become injured by the horses and by the wheels, while with the tractor outfit only four rows of the eight are injured. The question of the effect of wheel injury has already been fully discussed.

Comparison of Dust and Spray

In the main series of plots, already described, wherein different copper fungicides were compared, copper-lime dust did not compare favorably with Bordeaux mixture. Further comparison of dust and spray is considered desirable here, with special reference to certain practical problems such as amount of dust applied and condition of the foliage at the times of application.

In the eight years' comparison of copper-lime dust and standard Bordeaux mixture on Aroostook Farm, a fairly successful attempt has been made to apply the same amount of copper in the two kinds of material in any one season. Copper being the essential part of these materials in their functioning as fungicides, and dust being generally unfavorably reported on from other regions, it seemed unfair to dust to reduce its copper content to less than was considered necessary in the spray. This idea has been confirmed by observations in commercial fields where smaller amounts of dust were used, and by chemical tests which showed that the

copper applied in dust did not adhere as well as that applied in spray (Folsom and Bonde, 1926, pp. 273-278; Bonde *et al.*, 1929, pp. 127-130). However, as it costs more to apply the same amount of copper in the dust than in the spray, due to the cost of factory-mixed materials (Folsom and Bonde, 1926, pp. 272-273; Bonde *et al.*, 1929, pp. 135-136), the question has arisen of the effects of applying dust on an equal-cost basis rather than on an equal-copper basis. The importance of this question has been emphasized by our results with reduced strength in Bordeaux mixture and by various commercial and extension agents. Consequently, to the spray-dust comparisons of 1931 already described, were added comparisons with less dust applied per acre.

In our copper-equivalent experiments we used approximately 28 pounds of 9 per cent dust for each 100 gallons of 5-5-50 Bordeaux mixture. Local dealers recommended in 1931 that the first two applications of dust be light, each consisting of 15 pounds. It was further recommended that the amount of material be increased to 20, 20, 25, and 30 pounds respectively for the following applications. According to the dealers it should not be necessary to use more than 100 to 150 pounds of 9 per cent dust per acre for the season.

The 1931 dust schedule followed to conform with the recommendation of some dealers in dust equipment and materials, will be designated here as the "light-dust" series. Three light-dust applications of 15 pounds each were applied in July. The amount was increased to 22 pounds on August 7, and on August 17 and 25, respectively, 24 and 25 pounds were used. Fog was extremely heavy the latter part of August so that on August 22, 23, and 24, late blight spread very rapidly in fields that were not properly protected. All of our dusted plots suffered during this period. As a result of the lack of control secured with the above amounts of dust, three additional applications were made as follows: August 27, 30 pounds; August 31, 28 pounds; and September 5, 25 pounds. The total amount of dust used for the season was 199 pounds per acre which is considerably more than the amount generally recommended. The 199 pounds contained 18 pounds of copper.

The above dust program was carried out in two series of plots. One series of plots was dusted while the foliage was wet

and the weather calm, generally during the early morning. It was attempted to dust the adjoining series of plots while the foliage was dry and the wind more or less brisk. During the season it was at times difficult to find the dry conditions called for in this set of tests. At times it happened that rainy weather prevented the application to dry foliage as outlined in the plans.

DISEASE CONTROL

Adjoining plots that had been sprayed with Bordeaux mixture on approximately the same dates as those receiving the light dust schedule, remained free from late-blight infection throughout the entire season. Late-blight spots were observed to be quite general on July 27 in the plots that were dusted while dry. The plots in this series were the only ones on Aroostook Farm that were infected at that early date. By August 25, 40 per cent of the foliage in both series of light-dusted plots was dead and on September 10 these plots were 85 to 90 per cent dead. This information indicated clearly that the dust as used in these tests was distinctly inferior to the Bordeaux. In the nearby main series of plots, those receiving 31.44 pounds of dust per application or 283 pounds for the season had foliage free from blight until August 16 or several weeks later than the plots receiving light dust. However, at the time of severe blight spread (August 22, 23, and 24) these plots also rapidly became infected and were soon defoliated. These data indicate that not even heavy, let alone light dust applications, effectively control late blight if the conditions are severe, while Bordeaux is satisfactory. Greater amounts of dust may decrease the amount of early infection without giving either a correspondingly greater yield or satisfactory disease control later in the season.

At the end of the season there was no great difference in the degree of infection between the two series of "light-dusted" plots. Those dusted while the foliage was dry became infected earlier and developed several badly diseased areas. In general it seemed that those plots that were dusted while moist remained slightly greener throughout the season than did those dusted during dry and windy weather. The difference in disease control was slight, however, and apparently not enough to cause any significant difference in yield.

Generally it has been advised to dust wet foliage. Boyd (1926, p. 63) found that late blight, early blight, flea beetles, leafhoppers, and tipburn were more effectively controlled by dust if applied to moist foliage. The writer's observations indicate that calm evenings before heavy dews might be the most ideal time for applying dust. At such a time it appears that there is a more even distribution of dust with little or no excessive clumping of the particles such as occurs when the droplets of moisture accumulate and run together. There also seems to be less drifting and blowing away of materials, so that often a dust fog may be seen to remain over a recently dusted field for over an hour. There is also the added advantage that less foliage injury and soil packing occur if the duster is used on dry foliage and soil.

YIELD COMPARISONS

Our previously reported experiments (Folsom and Bonde, 1926, p. 244; Bonde *et al.*, 1929, pp. 114-115) have failed to show appreciable differences in yield between dusted and sprayed plots. Both of these treatments when properly used gave good commercial control of disease under Aroostook conditins. The relatively small numbers of harmful insects, the absence of tipburn, and the fact that leaf diseases were not especially serious, were probably factors that greatly favored the results obtained with dust.

As in the year 1930, and as expected from the lack of disease control, the yields of dusted plots in 1931 were inferior to those of sprayed plots. This has been pointed out previously for the main series of plots which contained some that were "heavy-dusted." The light-dusted plots yielded within one bushel per acre of the heavy-dusted. Both dusted series showed practically the same decrease below adjacent Bordeaux plots. The difference in yield between each series of dusted plots and the corresponding sprayed plots was highly significant.

CONCLUSIONS REGARDING THE RELATIVE MERITS OF DUST AND SPRAY IN AROOSTOOK COUNTY

Yield comparisons have been conducted on Aroostook Farm for eight years, with respect to copper-lime dust *vs.* Bordeaux

mixture. The results are summarized in Table 9. It may be noted that for the six years, 1922-1925 and 1928-1929, the average yields for these two fungicides were the same. The fact that dust did not control the leaf diseases as well as Bordeaux mixture was not manifested by a reduction in yield. The data for 1930 and 1931 show that a six-year period was insufficient time in which to test the relative merits of the dust and Bordeaux. With late blight very prevalent, the dusted plots in these two years yielded respectively 32 and 31 bushels less per acre than did the sprayed plots. For the eight years, dusted plots yielded on the average approximately 8 bushels or 3 barrels less per acre than did Bordeaux-sprayed plots.

TABLE 9

Comparison of Yields from Sprayed and Dusted Plots for an Eight-Year Period[1]

Years	Average yield per acre				Difference in yield	
	Bordeaux mixture		Copper-lime dust			
	Bushels	Barrels	Bushels	Barrels	Bushels	Barrels
6-year average, 1922 to 1925 and 1928 to 1929	355	129	355	129	None	None
1930	384	140	352	128	32	12
1931	414	151	383	139	31	12
Average for 8 years[2]	366	133	358	130	8	3

[1] From data in Table 1.
[2] Average for untreated check plots being 338.5 bushels or 123 barrels.

This small average difference of 8 bushels per acre would not be sufficient to influence users of dust to change their practices and adopt the use of Bordeaux mixture. Dusting has certain advantages over Bordeaux and is better for some growers. There is no doubt but that dusting is much faster and easier than spraying. Some growers are handicapped because of the lack of a suitable water supply in which case dusting might be preferred. It is also claimed that dusting requires less careful supervision and can be done with less skilled help than spraying. Either method must,

however, be thorough and must be carefully employed if satisfactory results are to be obtained.

The chief disadvantages of dust as a potato fungicide are briefly as follows: The cost of material is considerably more for dust than for Bordeaux especially if equal amounts of copper are applied. (This cost is not fully balanced by the lessened cost of labor due to greater speed of application.) If home-made dusts are used the cost item is greatly reduced, however. In years of serious disease epidemics dust can generally not be expected to give as good disease control as Bordeaux mixture. Dusts are also generally considered as being less effective against tipburn and hopperburn and against flea beetle injury. These latter troubles, however, are generally of minor importance, or even absent, in Aroostook County.

As is brought out by Gratz (1930 and 1930a) the economic advantages of spray over dust cannot be determined entirely by the actual costs of the materials used. The difference in net returns is obviously greater as the selling price of potatoes increases. Since spraying may be generally expected to yield more than dusting, the differences in net returns to the growers may assume large proportions, depending upon the differences in yields and the selling prices of potatoes. This fact is of course as true for Maine as for Florida and other regions.

In conclusion we may say that dust if properly used will give good commercial control of diseases in Aroostook County and may be safely used as a substitute for Bordeaux mixture, on a long-time basis, though costing more and giving less satisfactory results in seasons of severe late blight.

The climatic conditions in the potato growing regions of New Brunswick, Canada, are very similar to those of Aroostook County, Maine. MacLeod (1930), in his studies on potato spraying in New Brunswick, arrived at much the same conclusions, regarding the relative merits of dust and spray, as has the writer. Briefly he concluded (MacLeod, 1930, p. 35) that Bordeaux mixture on the whole showed significant increases in yield over that produced by copper-lime dust. Both fungicides in most cases increased the yield substantially over that produced by the checks. Copper-lime dust was, however, in most cases equally effective in the control of late blight during normal seasons. The fact that the writer's results

confirm to a large extent those got by MacLeod under very similar climatic conditions, adds additional value to the data secured in Aroostook.

INSTANT BORDEAUX

Experimental results with instant Bordeaux in 1931 have been described previously. With "power take-off" and with large fields and long distances to the water supply, there probably is need for such a Bordeaux mixture as can be prepared in the sprayer in the field. Sanders in 1918 (1918, p. 83) called attention to a quick and convenient method of preparing Bordeaux mixture.[10] In 1922 the Oregon Agricultural Experiment Station (Robinson, 1930, pp. 14-15) recommended a Bordeaux preparation referred to as "two powder" Bordeaux. Schneiderhan (1929a) introduced this method as "instant Bordeaux" to the farmers of Virginia and West Virginia where it is said to be gaining in popularity. Instant Bordeaux has also given satisfactory results in tests conducted in Michigan (Wheeler and Moore, 1930, p. 93).

The method for making instant Bordeaux as given by Schneiderhan (1929, pp. 239-240) is as follows:

Steps in the Preparation of Instant Bordeaux

1. To prepare 100 gallon tank of 4-4-50 Bordeaux mixture, weigh out 8 pounds of "snow" (powdered copper sulphate) and 8 pounds of chemical hydrated lime.
2. Fill the spray tank one-fourth full of water and start the agitator, being sure that it works properly.
3. Add the powdered copper sulphate by pouring it onto the tank screen and washing it into the tank with the inflowing water. Keep the water flowing into the tank while the agitator is running.
4. Add water to the tank until it is three-fourths full and by this time the copper sulphate will be dissolved.

[10] Bordeaux made by this method was then called the "quick time" Bordeaux and according to Sanders (through correspondence) is still commonly used by fruit growers in Nova Scotia.

5. Next add the chemical hydrated lime, either as a paste or in the dry form by pouring it on the screen and washing it into the tank as in the case of the copper sulphate.
6. Now fill the tank with water and run the agitator a minute or so longer and then the Bordeaux is ready to be sprayed.
7. The agitator must be kept running continuously during the entire mixing operation.

The comparative yields as given in Tables 4 and 8 speak quite favorably for the use of instant Bordeaux. This material has given as favorable disease control (Table 7; Figures 17 and 18) as has Bordeaux mixture prepared by the standard method of pouring diluted stock solutions into the sprayer at the same time. One question is whether or not the preparation of instant Bordeaux will be more convenient than the standard method. The instant-Bordeaux process will eliminate the use of the stock solution barrels, which at times is inconvenient. In many cases farmers do not have permanent mixing platforms and are long distances from a suitable water supply. Under such conditions the water might be advantageously hauled by trucks and the Bordeaux made in the field. Whether this procedure will meet with the approval of the growers remains to be seen. The extra cost involved by using pulverized copper sulphate instead of the crystalline form is not a very large factor. The cost would probably be from two to four cents per pound more.

Burgundy Mixture ("Sal-soda Bordeaux")

The experiments with Burgundy mixture (in Aroostook generally called "sal-soda Bordeaux") carried on in 1931 have been described. This mixture has not become very common in Maine. There are, however, some potato growers who prefer it to Bordeaux mixture. Observations in commercial fields in 1930 and 1931 revealed that Burgundy mixture where used had given very excellent disease control under severe tests. It also seems to be gaining in popularity because of certain advantages.

Pethybridge (1918) makes the following statement regarding Burgundy mixture in Ireland, "The first named [meaning Burgundy mixture in comparison with Bordeaux mixture] is undoubt-

edly, on the whole, more easily prepared and applied to the foliage; and its use is becoming more popular amongst farmers in Ireland every year." MacLeod and Richardson (1930) found that Burgundy mixture gave favorable results in New Brunswick, Canada, where the potato-growing conditions are much like those of Aroostook. It is apparent from the experiments of 1931 (see Table 8) that there will not be enough difference in yield to determine whether to use lime or sal soda for the preparation of potato fungicides.

Burgundy mixture has certain advantages, however, which briefly are:

1. There is no sediment left in the sprayer and hence there is no clogging of the sprayer parts.
2. Does not discolor the foliage. This appears to the writer to be a distinct advantage for Aroostook especially where it is desirable to detect the mosaic diseases. This would greatly help to increase the efficiency of the disease-roguing operation. There is also the added advantage (in the writer's opinion) that the smaller amount of shading would be beneficial.
3. It is claimed to be a superior fungicide against late blight and early blight.
4. Butler and Smith (1919) maintain that Burgundy mixtures are more adhesive than Bordeaux mixture.
5. There is also probably less abrasive action in the sprayer nozzles due to the absence of gritty particles in the solution.

Among the objections to Burgundy mixture are listed the following:

1. The cost of preparation is somewhat greater for Burgundy mixture. The difference in cost, however, is relatively small and not a large factor.
2. Burgundy mixture is said to have less stimulating effect on the potato plants than Bordeaux mixture (MacLeod and Richardson, 1930, p. 160). Whether this actually is a factor might be questioned, judging from our tests on supposed stimulation. (See pp. 216 and 226).
3. Sodium carbonate, of a kind that is always free from undesirable impurities, is said to be more difficult to obtain than

suitable lime. However, sodium carbonate that is suitable for spraying could probably be secured in quantity provided there is a demand for it.

4. It apparently cannot be combined with the brands of lead arsenate used commercially, but on Aroostook Farm calcium arsenate has been successfully used in combination with it.

5. It has been considered that Burgundy mixture is sometimes toxic to the potato foliage.

6. Some growers feel that this mixture has a corrosive effect on the spray boom.

Anderson and Roth (1923, p. 54) in their book on insecticides and fungicides give the following formula for the preparation of Burgundy mixture.

Burgundy Mixture

Field Formula	
Copper sulphate	1 lb.
Sodium carbonate (sal soda)	1½ lbs.
Water	50 gals.

According to their formula the ratio of copper sulphate to sal soda is 1 to 1½. This ratio apparently is the one most commonly recommended. Various Aroostook farmers have stated that they were using the formula 5-5-50 or a 1 to 1 ratio. This formula gave good disease control with no apparent foliage injury. Judging from the results obtained by farmers it seems advisable or at least satisfactory to use equal amounts of copper sulphate and sodium carbonate.

COLLOIDAL COPPER AND OXO BORDEAUX

In 1927 an experimental colloidal-copper spray[11] gave very promising disease control and yield results. (Bonde *et al.*, 1929,

[11] This was made with colloidal-copper paste which was supplied by Dr. Frank Wilcoxon through the courtesy of the Nichols Copper Company of Laurel Hill, New York.

pp. 108-109.) A commercial preparation termed Oxo Bordeaux[12] also gave good disease control in 1928. In 1931, Oxo Bordeaux was included in the main series of plots. This preparation yielded as well as did any of the fungicides used. (See Table 8.) The general appearance of the foliage in the plots sprayed with Oxo Bordeaux was superior to that with any of the treatments until in late summer when late blight became prevalent. Oxo Bordeaux applied at the low concentration used (1 per cent metallic copper) apparently could not give the necessary protection against a severe attack of late blight.

It is of interest that in our experiments colloidal copper and Oxo Bordeaux have given the best appearance to the plants in the field. In these tests the amounts of metallic copper were greatly reduced which may possibly be responsible for the better appearance of the potato foliage. The colloidal copper also leaves a transparent residue on the leaves which might help to improve the general appearance and vigor of the foliage. Finally, transparency of residue would assist in roguing mosaic.

COMPARISON OF STONE LIME AND HYDRATED LIME FOR THE PRODUCTION OF BORDEAUX MIXTURE

In the past it has been considered by many that stone lime was better suited to the making of Bordeaux mixture than hydrated lime. Recommendations to the farmers in Pennsylvania (Pennsylvania Cir., 1929; Nixon, 1920; Nixon, 1922; Nixon and Hodgkiss, 1922) have been particularly insistent on the use of stone lime in the spraying operation.

On the other hand, in states adjacent to Pennsylvania, Martin (1930, p. 158) in New Jersey and Tilford (1928, p. 192; 1931, p. 150) in Ohio found that hydrated lime of good quality is as desirable for Bordeaux mixture as stone lime. The same is reported by Gratz (1930, p. 147) in Florida. Hydrated lime has been successfully used in the preparation of Bordeaux mixture in Massa-

[12] This preparation was supplied by the Ansbacher-Siegle Corporation, New York, through G. E. Sanders, their Entomologist, who states that as applied the material is in a colloidal form.

chusetts (Holland and Gilligan, 1927) and New Hampshire (Butler, 1928, p. 190), which are close neighbors to Maine. Recommendations issued in various states show that hydrated lime is now in general use. More recently, emphasis has been placed on "chemical hydrated lime" as being more suitable than other kinds of hydrated lime, especially for instant Bordeaux.

In recent years there has been more or less agitation in Aroostook County for the use of stone lime. It has been claimed that the failure of many growers to control late blight successfully was to a large extent due to poor-quality Bordeaux made with hydrated lime. Although we have never experienced poor disease control with hydrated lime on Aroostook Farm it was thought advisable to conduct some direct comparisons between Bordeaux mixtures prepared in the two ways. Woods (1903, p. 192) reported that Bordeaux in which "prepared lime" had been used was as effective against blight as that made with the usual grade of stone lime then available, but the writer is not aware of any other comparative tests having been made in Maine until those of 1931 which are now to be reported in this bulletin.

In this comparison a 5-5-50 formula was used for both types of Bordeaux. Eight applications were made during the season applying approximately 1,155 gallons of spray. The spray was applied with the 8-row tractor-power sprayer carrying 400 pounds pressure. The two treatments were in each case adjacent to each other in the field so that direct comparison could be made under very similar conditions. The plots were 3 rows wide and 150 feet long. Yields were obtained from 15 replicated plots.

Both kinds of Bordeaux mixture gave perfect control against disease during the extremely severe late-blight epidemic of 1931. It was not possible to establish that either kind of Bordeaux was superior to the other. The yields were about 470 bushels an acre and differed by only 3 bushels with a probable error of over 5 bushels, which gives no proof of superiority.

The writer in the spray tests conducted on Aroostook Farm has not experienced great difficulties in the use of hydrated lime for the preparation of Bordeaux mixture. The Bordeaux made with hydrated lime has in all cases given excellent disease control under both experimental and commercial conditions. Bordeaux made with stone lime is said to adhere better than that made with

hydrated lime. The difference is, however, not great enough to offset the difficulties encountered in properly slaking stone lime. It is doubted that stone lime will ever be extensively used for the preparation of Bordeaux mixture in Maine.

OMISSION OF EARLY FUNGICIDAL APPLICATIONS

Generally it has been recommended that growers should commence the spraying or dusting operations early in the season while the plants are still small. Growers usually are very particular to begin to spray at an early date. (In fact, at times it seems as though they pride themselves in beginning to spray before their neighbors do.) However, certain insects and diseases that necessitate early spraying in other regions, are not serious in Aroostook. Therefore the early spray applications, that seem to be so essential in some potato regions, are not so important in Aroostook County.

In 1926 (Bonde *et al.*, 1929, pp. 123-125) a delayed program for the application of fungicides was followed on one part of Aroostook Farm. The plot was dusted for the first time on August 18, four days after late blight had been observed and seen to spread. In all, five applications (200 pounds) were made. Blight was checked considerably but not as much as in plots sprayed the regular seven times. At the same time, "one application made through error on a check plot on August 25 gave practically as good control of foliage infection and gave the highest yield per acre of the 6 plots of this test" (Bonde *et al.*, 1929, p. 102).

In 1928 (Bonde *et al.*, 1929, pp. 125-126) a delayed-spray program and a delayed-dust program were compared with the regular spray schedule. In these tests the plots that received five late applications were superior in general foliage appearance to those that were given eight applications, although late blight was not controlled quite as well in the former. The yield for the delayed schedule was also somewhat greater than that of the regularly sprayed field. The average yield was 392 bushels (143 barrels) for the delayed program and 372 bushels (135 barrels) for the plots receiving the regular number of applications. The difference in yield was, however, not significant.

In 1929, foliage diseases were not serious and spraying was postponed until early August. In these tests early blight became

quite prevalent. Yields from other very similar plots would indicate that the amount of disease present was of little or no consequence.

In 1930 the series of plots used to test the effect of reduced concentrations of Bordeaux mixture were not sprayed until July 15, at which time late blight had begun to spread. In these experiments, even with the reduced strengths of Bordeaux (½ and ⅔ strengths), the delay showed no ill effect.

In 1931, the plots comparing hydrated lime and stone lime for the preparation of Bordeaux were sprayed for the first time when the foliage was 15 inches high. The disease control in this test was excellent in spite of the delayed application and the favorableness of the season for late-blight spread.

Finally, for several years the commercial spraying done on Aroostook Farm has been done according to a delayed-spray program, with excellent results. This leads us to a consideration of the special tests in 1931.

TESTS IN 1931

The early evidence of late blight (July 3) in 1931 made a severe late-blight epidemic appear possible and so prompted the further testing of a delayed-spray program. A series of plots that received nine applications of the standard Bordeaux mixture, applied with the tractor-power equipment, was compared with plots that had the first 3 applications omitted so that they received only six applications. These six late applications were made in some plots with a tractor-power machine and in others with a wheel-traction machine. Spraying on the plots receiving the complete schedule began on July 3. The delayed schedule was begun on July 28, when late blight was quite generally scattered throughout the unprotected foliage.

The difference in disease between the two delayed-spray series of plots and those sprayed according to the complete schedule was not as striking as might be expected. In general the horse-drawn wheel-traction outfit did not give as good disease control as did the tractor-power machine. Two small infected areas and some stem and leaf spotting developed in the delayed-spray wheel-traction plots. This infection was a continuation of the initial infection

that had taken place before spraying was begun. The amount of late blight in the tractor-power plots was negligible for both the delayed and the complete series.

These results show that late blight can be checked with either a wheel-traction or a tractor-power outfit. The tractor-power machine, capable of applying more material with higher pressure, is more desirable when late blight has become started in a field. Such equipment is, however, not essential in all cases as was shown in this test.

The average yields from the several series of plots and their respective positions in the field are listed in Table 10. The data

TABLE 10

Effects on Yield of Omitting Early Spray Applications in 1931

Treatment[1]				Yield per acre	
Schedule[2]	Machine	Gals.[3]	Lbs. copper[3]	Bushels[4]	Barrels[5]
Complete	Power take-off	1283	32.66	407±6.28[6]	148
Delayed	Wheel-traction	590	15.02	405±4.61	147
Delayed	Wheel-traction	590	15.02	404±5.98	147
Delayed	Power take-off	880	22.40	414±6.85	151

[1] Listed in order as the series of plots occurred in the field.
[2] The complete schedule included 9 applications of 5-5-50 Bordeaux mixture during the season and the delayed schedule omitted the first 3 applications.
[3] Rate per acre for the season.
[4] Each yield is the average for 6 plots.
[5] Determined by dividing the average number of bushels by 2.75.
[6] For P.E. formula see Table 3.

in Table 10 show that the delayed programs did not reduce the yields as might be expected. The yields are not significantly superior for any of the treatments, although there is a slight indication that the delayed power-spray program would yield the most if conducted in more extensive tests. The significant item in these data is that similar yield results were obtained with the delayed program at approximately two-thirds the cost. According to our previously estimated cost records (Folsom and Bonde, 1926, p. 245) this reduction would amount to $3.69 per acre for the season.

Conclusion on Omission of Early Applications

In conclusion it is seen that it is possible to reduce the number of applications without reducing the yield. However, as we have stated previously (Bonde *et al.*, 1929, p. 127) the results vary with the season, the source of the disease (whether from an early-infection spot in the field or from other fields), the soil and location, the amount of vine growth, the time of spread of the disease, the times of applications, the nature of the fungicide, etc. At present it seems that the safer practice is to begin spraying relatively early in the season and continue until frost. The practice of omitting the early spray applications until blight is beginning to appear can be more safely done with a tractor-power sprayer than with the less efficient horse-drawn wheel-traction sprayer.

It is not advocated here that the early spray applications be omitted but it is felt that they have been given too much emphasis in Aroostook. As will be shown in the next section of this bulletin, the applications made in late summer and early fall are generally the most critical and need additional attention.

OMISSION OF LATE SPRAY APPLICATIONS

As was shown in the disease surveys conducted in 1930 and 1931 (to be described later) it is a very common practice for farmers to omit or neglect the late spray applications, meaning those of the last of August and of September. Stuart (1928, p. 255) calls our attention to this fact by the following statement: "Many years' observation has shown conclusively that all too frequently growers have ceased spraying before it was really safe and as a result have in many instances suffered heavy losses through late blight infection of the tubers when perhaps an additional application might have largely, if not entirely, prevented the infection." The observations of the writer confirm those of Stuart. The writer is of the opinion that the majority of failures to successfully control late blight can be attributed to the practice of discontinuing the spray operations too early in the season. Very often growers spray very carefully during the early and middle parts of the potato-growing season but discontinue this practice

at a time when the conditions are most critical for the development of the disease.

A common opinion prevails that spraying injures the foliage of Irish Cobblers and hastens maturity if applied after they are in bloom. We have no evidence to confirm this idea; in fact, spraying has appeared to retard growth. There is also a very strong feeling that it is unwise to drive through heavy potato foliage with a spray rig because of excessive vine injury. This has led to the discontinuance of the spraying operations when there was most need for them. The effect of vine injury on yield has been discussed previously in this bulletin. In years when blight is extremely prevalent and spreading rapidly, it becomes an important question to decide whether it is more desirable to spray and cause losses through vine injury or to not spray and suffer losses from disease.

TESTS IN 1931

In 1931 a portion of a field was sprayed in a manner followed by many farmers. Three thorough applications were made during July. When late blight appeared, in the early part of August, another application was made. Spraying was discontinued when the vines became extremely large.

Blight spread very rapidly from August 13 to 15 and from August 22 to 24, and the plots where the late applications had been omitted soon became defoliated. On August 25 it was estimated that these plots were 50 per cent dead and a few days later the tops were practically all dead. This condition was almost identical with that observed in farmers' fields that had been treated in much the same manner. The yields obtained from the plots on Aroostook Farm throw some light on the losses that result from such a spray program. These plots gave 328 bushels an acre, which was 86 bushels (31 barrels) less than the 414 bushels obtained from plots receiving the complete schedule of 8 applications.

It is of interest also to compare the yields obtained from these plots, where the last applications were omitted, with plots that received no spray. While the omission of the last applications resulted in a decrease of 86 bushels (31 barrels) in yield, in a nearby series plots that received no spray yielded 108 bushels (39 barrels) less than adjacent plots that received the full number of

spray applications. From these figures it appears that with the late spray applications omitted, late blight may result in a reduction of yield almost as great as that obtained when no spraying is done throughout the season.

We should here compare the difference that exists between omitting the late sprays and omitting the earlier sprays (those of late June and July). As has been shown, the delayed spray program gave yield rates equal or superior to those of similar plots where spraying began early and was continued througout the season. (The yields for that test were 407 bushels for the complete spray program and 414 bushels for the delayed program.)

Discussion on Omitting Late Applications

It is thought that the value of the late fungicidal applications should be more fully appreciated by the potato growers in Aroostook County. It is evident, however, that the value of these late spray applications depends on several factors including variations in seasons relative to disease, the maturity of the plants when affected, and the variety grown.

In years of very little disease, omitting the late sprays (in fact all of the sprays) might not greatly affect the yield. Huckett has shown the relationship that exists between the date of planting and yield. For Long Island (Huckett, 1930, p. 27) he makes the following statements relative to this question: "It was evident by these results that the potato crop in certain sections of Long Island could to a large extent be 'made' before the season arrived for the outbreak of more serious insect pests and diseases." He also states (p. 30), "Further, the benefit derived from later sprayings varied according to the age or development ot the plant. Where potatoes were planted very early there was no evidence that later spraying increased the yield. Where potatoes were planted later there was evidence that the benefits derived from later spraying increased according to the lateness in planting."

In Maine the growing season is relatively short and the differences in time of planting may be rather small. However, it often occurs that some fields will be one or two weeks nearer maturity than others when blight becomes prevalent. If blight becomes serious before the crop has been largely "made," and when the tubers are growing rapidly, the loss may be enormous.

Early varieties, such as Irish Cobblers and Bliss Triumphs, may suffer much less from late blight than Green Mountains and Spaulding Rose 4 because they often have reached their maximum tuber formation before the disease has become serious. For this same reason the late spray applications are more likely to be less important for the early varieties than for the later maturing ones.

YIELDS FROM SPRAYED AND NON-SPRAYED PLOTS HARVESTED AT DIFFERENT DATES

During the summer of 1931, comparative yields were determined for sprayed and non-sprayed plots harvested at approximately weekly intervals. The yields were secured from fifty-foot lengths of row. The sprayed and non-sprayed plots were separated by two buffer rows to avoid any effect caused by the drifting of the spray material onto the unsprayed control plots. Mechanical injury was avoided by using rows No. 2 and 7 sprayed by the tractor-power machine in an 8-row strip. The tubers were dug by hand and weighed. The two kinds of treatments were replicated four times for each of the first three harvestings and six times for each of the last four. The weights of the tops were included in these data because they show the relative condition of the foliage for the different dates and give a clue as to the effect of late blight at different dates throughout the summer. The average yields and the weights of the tops for the sprayed and non-sprayed plots harvested at different dates are summarized in Table 11.

The data showing the yields for the different dates are interesting and throw some light on the question of the effect of spraying on yield. It is to be noted that on August 8 and 15 the non-sprayed plots yielded somewhat more than those sprayed, and that they had somewhat more tops at this time. These data, although not highly significant, suggest that the spray material may have an injurious effect on the foliage in the absence of blight. It was at least shown that the spray material did not cause a stimulating effect that was manifested in the yield or in top growth.

Although blight was present in the non-sprayed plots, the effect of disease on the yield does not appear until after August 24. It is noted that the weight of the foliage in the unsprayed plots

decreased rapidly after August 15. The decrease in weight of the tops in the sprayed plots was less rapid and was due to natural ripening and dying.

TABLE 11

Yields[1] and Weight of Tops from Sprayed and Non-sprayed Green Mountains Harvested at Different Dates in 1931

Date harvested	Sprayed[2]			Not sprayed		
	Yield in bushels	Yield in barrels	Weight of tops (lbs.)	Yield in bushels	Yield in barrels	Weight of tops (lbs.)
Aug. 1	206	75	88	205	74.5	84
8	246	89.5	70	265	96	76
15	314	114	70	327	119	77
24	354	129	46	350	127	30
31	376	137	50	342	124	19
Sept. 8	420	153	40	320[3]	116[3]	8
16	428	156	15	351	128	5

[1] Yields are the averages for four fifty-foot lengths at each of the first three harvestings and for six fifty-foot lengths at each of the last four harvestings.
[2] These plots received nine applications of 5-5-50 Bordeaux mixture for the season. The amount of spray used per acre was 1,283 gallons containing 32.66 pounds of metallic copper.
[3] Late-blight tuber rot was prevalent in the unsprayed plots of this series which accounts for the low yield.

These data again show the value of the late sprays. In the plots that were not sprayed, the maximum yield was reached by August 24, while in those that were sprayed, tubers continued to develop until they were dug on September 16. It can readily be seen that this increase in the growth period was very important in determining the yield. It should be observed that prolonging the life of plants about three weeks increased the yield 74 bushels or 27 barrels per acre. This increase amounted to about 21 per cent of the entire crop for the season and would largely determine the amount of profits secured in normal price years.

SOURCES OF LATE-BLIGHT INFECTION

Tubers affected with late blight or "dry rot" are depicted in Figure 22. Melhus (1915, pp. 99-100) has shown in Aroostook

County that potato seed tubers infected with the late-blight fungus, *P. infestans,* may originate the development of an epidemic. The mycelium present in the planted seed piece grows up the potato stem where it sporulates. Murphy (1927) working in Ireland, found that the late-blight fungus commonly grows away from the diseased seed pieces and sporulates in the nearby soil. He further suggests that tillage operations, or the movements of soil insects (*Sciara*[13] sp.), may transport the fungus to a position from which the foliage may be attacked. From these initial sources of infection the inoculum is carried to the neighboring plants and then, provided the moisture and temperature relations are suitable, the rate of spread becomes extremely rapid. Thus it is seen that growers should be careful to avoid planting seed pieces affected with the late-blight fungus. Under practical field conditions, however, we have never seen infected stems that obviously originated from diseased seed pieces. There is no doubt that this may occur and it is of course possible that relatively few initial sources of infection may result eventually in a general epidemic.

In our studies on Aroostook Farm, spores of the late-blight fungus have been caught in abundance on glass slides during periods of severe epidemics, showing that the inoculum may be wind-borne. Moreover, generally the first infections seen on Aroostook Farm have been in small isolated spots on the upper part of the plant, suggesting that they occurred from aerial inoculation. In 1931, we observed late blight affecting the lowest leaves in places where they come in contact with the moist soil. This suggested that the lowest leaves of the plant become inoculated from the organism blown onto, or borne in, the soil. These facts are mentioned here to show there is need for further study regarding the factors determining epidemics and the source of the earliest infection. We should also know the reason why tuber decay is severe in certain soils and less important in others. This question also needs further study.

SOIL DIFFERENCES IN RELATION TO TUBER ROT

Late blight under certain conditions may cause great losses to the potato crop in the form of tuber rot. On Aroostook Farm,

[13] This genus of insects is included in the "Fungus-gnat" family, members of which have often been observed in the potato fields of Aroostook.

tuber decay has been negligible in well drained soil. The amount of loss in this better soil has varied from a trace to approximately one per cent of the total crop for both sprayed and non-sprayed plots. On wetter soil the amount of decay in some years has been considerable.

In 1930 the effect of soil type was clearly demonstrated in our spray plot experiments. The sprayed plots on the higher and drier soil (Caribou loam) had merely a trace of rot. In the lower areas, where the soil usually is wetter and darker and contains more organic matter (Washburn loam), the amount of tuber decay was comparatively large. In those places the amount of tubers left on the ground because of late blight rot was approximately 8 per cent of the total crop. Rot varied more in correlation with soil and slope than with the kind of spray treatment, even if the latter is considered to include the check plots.

Commercially grown fields in Aroostook County have been observed with from 25 to 30 per cent of the crop affected by late-blight decay at digging time. In these cases the rot has been associated generally with soil of the Washburn loam type.

That soil is a factor which greatly influences the amount of tuber decay caused by the late-blight fungus, has been previously recorded in Maine and elsewhere (Bonde *et al.*, 1929, pp. 132-133).

The reason that late-blight rot was more prevalent in the Washburn loam in 1930 can hardly be due to difference in length of life of the foliage because the plants in both types of soil were kept green until frost. It is, however, possible that humidity and temperature are more favorable for tuber rotting in the darker and wetter soil. It is in the lower areas that the late-blight disease is generally first observed. It has been noted that in the wetter soil the lenticels on the tubers may become slightly proliferated and enlarged. Whether or not this condition favors infection here is not known.

In many fields, spraying or dusting has been sufficient to give only partial control of disease. Under such conditions the living, partly diseased plants may serve as a continuous source of inoculum for infecting the tubers. In such cases more rot may occur in sprayed fields than in fields killed more rapidly by blight. This emphasizes once more the value of thorough spraying or dusting. The main point here, however, is that a similar phenomenon may

explain the greater amount of tuber-rot occurring in the Washburn loam. The environmental conditions in this type of soil may make good late-blight control more difficult. As a result enough disease can be carried along on the vines, in spite of spraying, to cause more tuber-rot than in the dry soil where conditions are less favorable for the development of late blight.

POTATO DISEASE SURVEYS IN 1930 AND 1931

The actual losses from "potato rust" or late blight are very difficult to estimate. The writer with Messrs. Beverly and Dolloff, County Agents of Aroostook County,[14] made surveys in 1930 and 1931 to determine the condition of commercial fields. Information was secured also on the spraying practices employed generally by the growers. From these surveys, together with the experiments, attempts have been made to discover the reasons for the too general failures of many potato producers in Aroostook County to control disease, and to estimate total losses. The information on the condition of the fields, obtained from these inspection tours, is summarized in Table 12.

As is seen from the data in Table 12, the losses due to late blight must have been enormous. When the surveys were made all Green Mountain fields should normally have been producing tubers very rapidly, but many were not doing so because of not having been properly sprayed. The dead fields and those with poor disease control as listed in the survey data of Table 12 had practically completed their tuber development for the season by August 24. Judging from the test of omitting the late applications and from the weekly harvesting records noted in Table 11, the crop was being increased in well-sprayed fields more than one barrel per acre for each day from August 24 to September 16. The crop was increased approximately 27 barrels in 23 days in the plots, which would represent the loss in most of the fields included in the surveys.

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[14] The Aroostook County Farm Bureau under the leadership of the local County Agents, Mr. Beverly and Mr. Dolloff, has been intensely interested in the disease surveys reported on here and have greatly assisted in their progress.

TABLE 12

Summary of Aroostook County Commercial Fields Included in Surveys of 1930 and 1931[1]

Year	Number observed	Number dead or with poor disease control[2]	Number with good or fair disease control	Percentage dead or with poor disease control
1930	670	553	117	82.5
1931	940	587	353	62.0

[1] Only Green Mountain fields were included in these surveys, which were made during the last week of August.
[2] Includes those fields where the plants were 80 per cent or more dead.

Other conclusions based on these surveys can be briefly summarized in the following statements.

1. It was evident that late blight can be controlled successfully in most sections of the County, provided that a vigorous spraying and dusting schedule is employed. All fields with good disease control had received from five to nine applications. The degree of control depended largely on the number of applications made from about July 14 to August 23. The early spray applications apparently were not the ones that determined the degree of disease control. One grower had good disease control where only the last four spray applications had been made. In the same field he failed to control late blight in a portion on which the last one of his six regular applications had been omitted.

2. In the majority of cases where failures to control late blight occurred, the growers had neglected the late summer applications. Most growers now practice early spraying rather than full-season or delayed spraying. Three men successfully controlled late blight with a tractor-power machine by spraying from six to eight times. One man was less successful with the same equipment because he omitted the later spray applications. Even with the best of equipment it does not seem justified to lessen the number of applications during an epidemic and while the foliage or tubers are actively growing.

3. A two- or three-day delay of one application, especially if the proper time was just prior to a rainy period, produced the difference between successful control and failure to control late blight in some potato fields, both in 1930 and 1931.

4. Farmers often neglect and delay their spray program because of other pressing duties especially during a critical late-blight period. Haying commonly was found to conflict with the spraying operations.

5. Several men had excellent results using the common horse-drawn wheel-traction rig with either one or two nozzles per row. It was apparent that their success was due to having made a reasonably complete series of applications especially at the most critical period.

6. Successful disease control was not dependent on the kinds of materials used. Good results were obtained with Bordeaux mixture prepared in different concentrations, with several kinds of dusts, with Burgundy mixture, and with Pyrox.

7. Many growers make a practice of greatly increasing the copper sulphate used in Bordeaux mixture especially during the latter part of the season. Some growers even double or treble the amount of copper sulphate in their formulae. Judging from our results on Aroostook Farm this practice is unneccessary if the standard formula has been used in the manner recommended.

8. The survey emphasized one fact in particular. Spraying and dusting for the average potato grower is purely a mechanical operation, conducted without much knowledge as to the principles involved. The writer feels that much could be accomplished in the field of general education pertaining to the nature of plant diseases and their control. It is thought that growers will get better results from spraying if they know something about how infection occurs and about the factors that influence disease epidemics. If they realize some of these fundamental principles they will be able to apply fungicides more intelligently and therefore more effectively. Many Aroostook farmers are still even unable to recognize late blight, especially during its initial stages. They often do not observe the disease before large defoliated areas are seen. Late blight is often recognized more by its "smell" than by its symptoms. Farmers should perhaps learn to be more observing in their fields and to be able to detect late blight when it first appears.

9. Finally, the survey showed how important the aggregate losses due to late blight may become in years of serious epidemics. That 82 per cent of the Green Mountain fields were badly infected in 1930, is a striking fact. In 1931, 62 per cent of the Green Mountain fields suffered greatly. Approximately 34 per cent of

the fields that were observed in 1931 were entirely dead at an early date. The reduction in yield, however, is extremely difficult to estimate. Tests on Aroostook Farm showed that the yield was reduced approximately 86 bushels per acre, or 20 per cent, in fields allowed to die early because of poor spraying. If Aroostook County raises about 80,000 acres of Green Mountains annually, as is probable, the loss in this variety alone would amount to about 2,350,000 bushels. This of course does not represent the entire loss resulting because of late blight in the above mentioned seasons. It has been further estimated (Bonde, 1932) that the reduction in yield amounted to about 3,760,000 bushels, or 7 per cent of the total crop including all varieties. Such a loss is as likely to occur in a good-price year as in one of low prices, and in either case is a respectable sum to be lost by failure to continue the spraying process through the last few weeks of the season.

SPRAY SERVICE FOR POTATO GROWERS IN AROOSTOOK

In 1928, during a late-blight epidemic, a local dust-selling agency took up the practice of issuing post cards to the farmers who were using its dust products, informing them of the prevailing disease conditions and advising heavier and more frequent dust applications. This procedure did not receive much notice from others until later in the season when it was observed that the dusted fields were superior to most of those sprayed with Bordeaux in the immediate vicinity. Further inquiry demonstrated that the disease warnings sent out by the dust agents had prompted the growers to dust at the most desired periods. The growers using dust commonly made their applications when they received a warning notice. This advice was followed not only by users of the one particular brand of dust but by users of the other dusts sold on the market. The growers using Bordeaux mixture on the contrary commonly delayed their operations until the disease condition was serious and disease spread was rapid and beyond control.

Some potato growers in Aroostook County have felt that they would be greatly benefited by receiving timely "spray warnings" regarding late blight. Such a "spray service" was initiated in 1931. This service involved notifying certain growers when late-blight

infection was first observed and then sending further statements as to the occurrence of weather conditions which favored the rapid spread of the disease and a general epidemic. This service was conducted by the County Agents, through the local Farm Bureau, with the aid of the writer.

The County Agents, by means of telephone, radio broadcasting, or the postal service, informed certain growers in the various parts of the County as to the existing disease conditions. The growers also received notifications of the time when it was intended to spray the potato plots on Aroostook Form. These notices had been previously addressed and were mailed immediately upon receiving the information from the writer. Special newspaper articles were often issued to supplement the spray warnings.

Eighty potato growers "signed up" with the Extension Service for the project. Their 80 fields of potatoes were distributed in different parts of the County and were grown under extremely varying conditions. None of the fields that were sprayed in accordance with the suggested spray program had serious difficulty with disease, according to reports received by the County Agents. The writer, with the County Agents, personally examined 48 of the fields included in the test. Of these 48 fields, 36 (75 per cent) had good disease control. In only four fields (8 per cent) was late blight poorly controlled. These were failures because of neglecting the spray program as advised by the spray service. We should recall that 62 per cent of the fields included in the general survey of 1931 in Aroostook were seriously damaged by late-blight attack. The great difference between the efficiency of disease control in the fields of the spray service and the general control that existed in the County, shows that the spray service either was signed up for by men who were better than the average at spraying, or that it stimulated them to improve their spraying practices. There was considerable improvement in their methods, judging from their reports.

Observations and reports for the past nine seasons indicate that when blight occurs in one locality of Aroostook, the prevalence of disease is in general very similar in the other parts of the County. For example, observations made in the southern part of Aroostook County may well serve as a basis for warning the entire County. Likewise blight observations made on our unsprayed plots on Aroostook Farm may quite accurately inform us what to expect

elsewhere. Local variations in temperature or showers have not seemed to greatly alter the general disease situation for the various potato-growing localities.

It does not appear entirely necessary to be able to forecast the weather accurately in order to issue spray warnings to potato growers successfully. Usually the first late-blight spots occur after a prolonged humid and warm period. These early infections are mostly quite general in a field and the rapidity of spread of course depends on the weather conditions that follow. If the weather should suddenly become unfavorable the spread of late blight would be rapidly checked. However, a return to favorable blight weather would again start the spread of disease, and it might be better to make an unnecessary application than to omit a necessary one.

The potato spray service as conducted does not necessitate additional trained help or expensive equipment. The men responsible for reporting the late-blight observations are constantly in the potato fields under the different conditions and can readily supply the needed information. Although the spray service, as conducted, may not entirely solve the potato spraying problem in Aroostook County, it does seem to meet a need.

GENERAL PRACTICAL CONCLUSIONS

This bulletin has presented the results of experiments extending over a three-year period. The data included were obtained in seasons differing greatly in the severity of disease and therefore gave very interesting and useful information. In 1929, late blight was practically absent in contrast with 1930 and 1931 when this disease was extremely severe. The spraying practices employed by the farmers and by the writer were given thorough tests during the disease epidemics that prevailed in those years. Extensive surveys of commercial fields were also made during the critical periods of the late-blight epidemics of 1930 and 1931, to discover the general practices employed by farmers and their success in controlling diseases. The great amount of loss suffered by growers because of the poor control of late blight justified a thorough study of the potato spraying and dusting problem in Aroostook County. Some of the data on practical questions set forth in this bulletin will be briefly summarized at this time.

The experiments conducted on Aroostook Farm and the data obtained from the surveys, have shown that potato rust or late blight can be successfully controlled during periods of epidemics, provided that the proper spray program is carried out. The inability to control disease well does not seem to be due to the type of fungicide or equipment used, but largely to the practice of discontinuing the spray operations too early in the season. Expensive high-pressure power machines, although desirable, are not essential for good late-blight control and high yields in Aroostook County.

Tests show that the late spray applications are more critical and essential for good late-blight control than are those made early in the season. It is not recommended that the early spray applications be discontinued but that more attention and consideration be given to the spraying operations during the latter part of the season. The practice should be to start spraying somewhat later in the season than is usually done and to continue until the vines are killed by frost. The intervals between successive applications should be from 7 to 10 days in seasons of late blight. During especially bad periods of disease spread it might be advisable to spray even more often than once every seven days.

According to our tests both copper-lime dust and Bordeaux spray may be expected to give good commercial control of disease. Dust is generally considered to cost more and is less effective than Bordeaux mixture especially in bad late-blight seasons.

The various spray materials used in these experiments have all given good yield results. Sal-soda Bordeaux made according to the ratio of one part of sal soda to one part of copper sulphate appears to be an excellent spray material and has certain advantages over standard Bordeaux mixture.

In Aroostook it has been shown that Bordeaux mixture has a depressing effect on the yield, especially in years of no late blight. This depressing effect can be diminished by reducing the concentrations of the materials used in the preparation of the Bordeaux mixture.

The conditions in Maine are somewhat different from those in other regions where insects and excessive heat are important factors to consider in the production of potatoes. The yield data for a 16-year period show that we may expect an annual average increase of about 29.5 bushels or 10.5 barrels per acre by applying spray or dust effectively. This is approximately 9 per cent of the

crop average of 328 bushels or 119 barrels. In some years, as is shown in Table 1, spraying may reduce the yield and in others the increase may be great. It is evident that the financial benefit derived from spraying in any one season depends to a large extent on the cost of applying the fungicide, the amount of disease present, and the selling price of potatoes.

SUMMARY

(1) The available records for the 16-year period from 1916 to 1931 indicate that the average increase that may be expected from spraying Green Mountains in Aroostook County is approximately 29.5 bushels or 10.5 barrels per acre. This is about 9 per cent of the average annual crop secured. The average yield for this 16-year period was 328 bushels or 119 barrels per acre. To increase this gain, is a problem requiring experiments of various kinds.

(2) The varied nature of these experiments and the non-uniform soil on which they were conducted, made the problem more difficult. It was necessary to have different sizes of plots and as many replications as possible in order to make a careful analysis of the results and to render the conclusions reliable.

(3) The effect of wheel injury should be given more consideration by both experimenters and growers. The amount of wheel injury varies with the row, the kind of machine, the length of boom, etc. In some rows it may reduce the yield 17 per cent.

(4) In 1929, with late blight practically absent, the application of full-strength Bordeaux mixture apparently decreased the yield. The highest yields were obtained from plots that were not sprayed or where the Bordeaux mixture had been reduced to one-half strength but these differences were not significant when considered biometrically. Copper-lime dust plots yielded the least.

(5) In 1930 and 1931, with late blight prevalent, the yield rate was significantly increased by spraying. This increase was approximately 75 bushels per acre.

(6) In 1930 there was no significant difference in yield between plots sprayed with low and high pressure respectively. A pressure of 230 to 300 pounds per square inch was as effective in increasing the yield as a pressure of 400 to 500 pounds when ap-

plied with the same tractor-power machine. The yield was less with a wheel-traction machine, due to a higher proportion of the rows being subjected to vine injury by the wheels. The yield with the tractor-power machine was greater with "instant Bordeaux" than with standard Bordeaux. These several treatments gave similar disease control.

(7) Bordeaux mixture used in reduced concentrations (2½-2½-50 and 3⅓-3⅓-50) gave good disease control and yields in 1930 even when subjected to prolonged periods favoring late-blight development. It apparently is not necessary to increase the strength of Bordeaux mixture during the latter part of the season as is often done by farmers.

(8) In 1930, copper-lime dust controlled disease better where applied to wet foliage than where applied to dry foliage. Dust applied by either of these methods was less effective in controlling late blight than was Bordeaux mixture containing the same amount of copper as the dust (25 pounds). In yield rate the dusted plots were inferior to those sprayed.

(9) In a series of plots conducted in 1931, copper-lime dust applied at the rate of 283 pounds per acre for the season (including 25 pounds of copper) did not control late blight as well as did Bordeaux mixture, and the yield was correspondingly less. Standard Bordeaux applied with the wheel-traction machine controlled late blight slightly less effectively than did Bordeaux applied with the tractor-power machine and there was a corresponding reduction in yield. The latter reduction in yield was, however, not entirely due to the difference in disease control but was due in part to the difference in the relative amounts of wheel injury caused by the two types of spray machines. Disease control and yield rate were similar with standard Bordeaux, instant Bordeaux, Burgundy mixture (sal-soda Bordeaux), and Oxo Bordeaux.

(10) In 1931, in a second series of plots, 199 pounds of copper-lime dust (containing 18 pounds of copper) controlled late blight about as well where applied to wet foliage as where applied to dry foliage, and the yields were similar. In both instances disease control was inferior to that secured with the application containing 25 pounds of copper. The yield, however, was the same.

(11) In the eight years from 1922 to 1925 and 1928 to 1931; dusted plots have yielded an average of 8 bushels or 3 barrels less per acre than Bordeaux mixture. Dust is about equal to Bordeaux

mixture in increasing yields in years with a moderate amount of disease. However, in years of serious late-blight epidemics, such as occurred in 1930 and 1931, dust is generally less effective in the control of disease than spray and the yield will be correspondingly less. The practical advantages of dust on some farms and the relatively small difference in yield will probably justify its use by some growers.

(12) The increased yield rates secured with instant Bordeaux in comparison with standard Bordeaux, and the greater ease of preparation, would seem to outweigh the greater costs of materials on certain farms.

(13) Burgundy mixture (sal-soda Bordeaux) has shown certain merits and might wisely be considered as a substitute for Bordeaux mixture by some growers. The fact that this spray material does not leave a spray residue on the leaves is an advantage in fields where it is desirable to rogue for the mosaic disease.

(14) Oxo Bordeaux, though containing much less copper, compared well with standard Bordeaux and left less residue to interfere with mosaic roguing. In spite of this reduced concentration of copper (1 per cent *vs.* 2.5) Oxo Bordeaux gave good yields, and because of it failed to give entirely satisfactory control of late blight.

(15) Bordeaux mixture made from stone lime did not prove significantly superior to Bordeaux mixture made with hydrated lime, in tests conducted in 1931.

(16) The yield was not affected by omitting the early summer applications and postponing the first spraying operations until blight was noted in the field.

(17) In 1931, the omission of the last applications resulted in a reduction of 86 bushels (31 barrels) an acre in yield. This was 4/5 as much loss as resulted from omitting all spraying, yield reduction in both cases being due to late blight.

(18) With mechanical injury absent, Bordeaux spraying reduced vine growth and yield rate until in late August when the control of late blight became an important factor.

(19) The immediate source of the first late-blight infection seems to be from the air in most fields, but is a problem requiring further attention. Diseased seed pieces should not be planted.

(20) In 1930 the rot due to late blight was evident in 8 per cent of the crop at digging, in certain places, but varied to smaller amounts with differences in soil type, slope, and drainage.

(21) Disease surveys were made the latter part of August in 1930 and 1931 in the various parts of Aroostook County. Of the 670 fields observed in 1930, 82.5 per cent were practically dead. In 1931, 62 per cent of the 640 fields noted were 80 per cent or more dead in late August. Judging from the yield in certain experimental plots the losses in the commercial fields of Aroostook must have been several million bushels each year.

(22) Conferences with growers during the surveys, indicated that poorness of control was not due so much to the kind of equipment and material used, as to stopping spraying too early in the season.

(23) A potato spray service was started in 1931 which improved the methods of some growers.

(24) It is concluded from the experiments and the surveys that late blight or "rust" can be successfully controlled even during periods of severe epidemics.

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FIG. 17. Green Mountain spray test plots on Aroostook Farm, August 28, 1930. I, instant Bordeaux applied with a tractor-power sprayer. W, standard Bordeaux applied with a wheel-traction machine. C, unsprayed check. The degree of darkness of color indicates the amount of late blight present.

FIG. 18. As for Fig. 17, looking in the opposite direction 5 days later. Note that late blight is severe in the plot where Bordeaux was applied with a wheel-traction machine, while still more severe in the check plot.

Fig. 19. Green Mountains on Aroostook Farm, September 2, 1930. C, unsprayed check. H, half-strength Bordeaux. T, two-thirds strength Bordeaux. Bordeaux applied here with a tractor-power machine.

Fig. 20. Green Mountains on Aroostook Farm, September 2, 1930. C, single row with one critical application (that of Aug. 14) omitted. Note the good disease control obtained on either side of C with a wheel-traction machine.

FIG. 21. Tractor-power machine spraying at 400 to 500 pounds pressure per square inch. Note the fine mist resulting from this high pressure. However, this pressure did not show any benefits over lower (see text, p. 188).

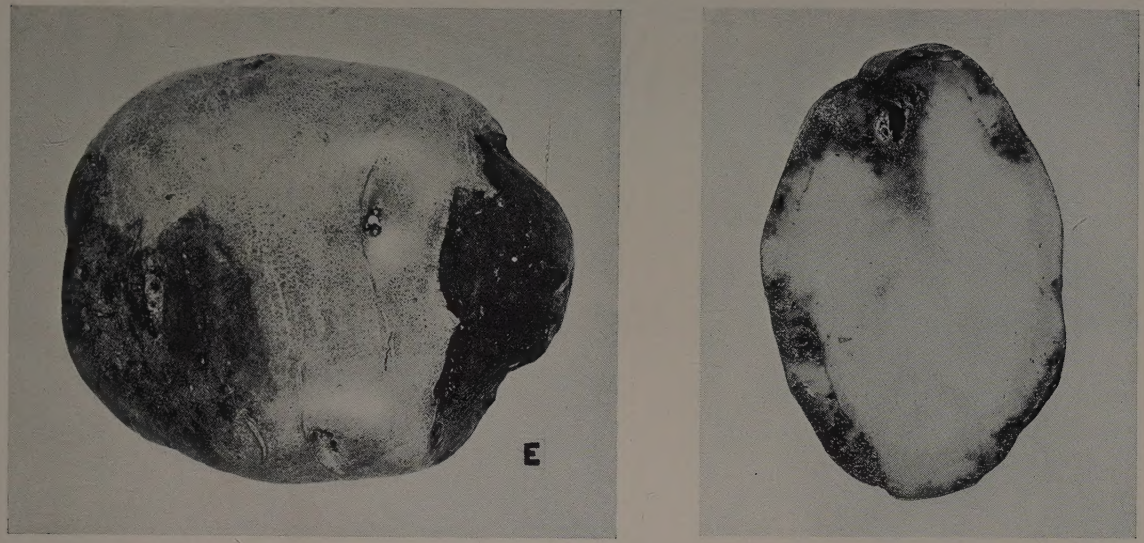

FIG. 22. External view of tuber affected by late blight (E) and cut surface of tuber affected by late blight.